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The impact of exercise-induced muscle damage on physical fitness qualities in elite female basketball players

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Abstract

The purpose of this study was two-fold. First, to examine the impact exercise-induced muscle damage (EIMD) on physical fitness qualities following a basketball-specific training session. Secondly, to determine the reproducibility of the sport-specific performance measures in elite female basketball players. Ten elite female basketball players (age 25.6 ± 4.5 years; height 1.8 ± 0.7m; body mass 76.7 ± 8.3kg) undertook a 90-minute training session involving repeated jumping, sprinting and game-simulated training. Indirect muscle damage markers (i.e., countermovement jump [CMJ], delayed-onset of muscle soreness [DOMS] and creatine kinase [CK]) and sport-specific performances (i.e., change of direction [COD] and suicide test [ST]) were measured prior to and 24 hours post training. These measures were also collected one week following training to determine the reproducibility of the basketball-specific performance measures. A significant reduction in lower-body power (-3.5±3.6%; P<0.05), whilst a significant increase in DOMS (46.7±26.3%; P<0.05) and CK (57.6±23.1%; P<0.05) was observed 24 hours post exercise. The ST was also significantly increased (2.1±1.8%; P<0.05), although no difference was observed for COD (0.1±2.0%; P>0.05). The intra-class correlation coefficient and coefficient of variation for the COD and ST were 0.81 and 0.90, respectively, and 1.9% and 1.5%, respectively. In conclusion, appropriate recovery should be considered the day following basketball-specific training sessions in elite basketball players. Furthermore, this study showed the usability of performance measures to detect changes during periods of EIMD, with acceptable reproducibility and minimal measurement error.

Keywords: Agility; suicide time-trial; reliability; muscle soreness; creatine kinase; countermovement jump

Introduction

Basketball is a team sport, demanding players to be agile while performing strenuous actions interspersed with active and passive recoveries (36, 37). For example, match intensity can reach up to 95% of maximum heart rate value, with players covering over 3% of the total running distance above $18 km \cdot hr^{-1}$ (30). Furthermore, players undergo quick transitions between offensive and defensive plays, with 576 transitions recorded during a full match (4). Accordingly, players are expected to train at a level equivalent to, or above, the physiological demands required during game-play. However, the typical movement patterns seen in game-play, such as jumping and repeated sprint efforts, are known to cause exercise-induced muscle damage (EIMD) due to a combination of eccentric and concentric muscle actions at a high intensity (13).

EIMD is typically accompanied by marked attenuation in muscular performance, delayed-onset of muscle soreness (DOMS), reduced range-of-motion and impaired kinaesthetic awareness due to the mechanical stress imposed on the muscle fibers and disturbances of calcium homeostasis (1, 14, 29, 32). Collectively, basketball-specific performances may deteriorate during periods of EIMD, impair training quality and ultimately compromise chronic training adaptation or increase risk of overtraining (8). Indeed, a number of studies have reported symptoms of EIMD via increased indirect muscle damage markers (i.e., vertical jump, DOMS and creatine kinase [CK]) for up to 48 hours following a basketball match in elite male (3, 35), elite female (23) and collegiate male (16) basketball players. Additionally, Chatzinikolaou and colleagues (2014) reported attenuated sprint, agility, and vertical jump performance for up to 72 hours after basketball match play in elite male basketball players. Conversely, Moreira et al. (2014) showed no changes in sprint and agility performance despite presence of EIMD 24-48 hours following a basketball match in elite female basketball players. These discrepancies may be due to differences in exposure to eccentric loading, given that exercise intensity during a basketball match is distinct between playing level and gender (24, 33). Nonetheless, the physiological stress during a full basketball match appears sufficient to cause EIMD even in highly trained basketball players. Whilst these findings highlight the need to provide sufficient recovery following a full basketball match, it is uncertain whether a basketball-simulated training session causes EIMD. Kostopoulos and colleagues (19) showed that a 10-minute basketball-simulated training session increased CK and impaired leg strength and knee range-of-motion for up to 96 hours post exercise. However, inferring the implications of these findings specifically to basketball is difficult given that basketball-specific measures were not included (e.g., sprint and change of direction and vertical jump performance), the training session was substantially shorter than that typically prescribed for elite basketball players (5) and the participants were recreational male basketball players. Given that some symptoms of EIMD (such as CK) are distinct between genders (17) and are considerably less in highly trained athletes compared to their lesser trained counterparts (39), the acute responses of a basketball-specific training session may differ in elite female basketball players.

Another consideration when monitoring the acute effect of a basketball-specific training session is whether the performance indicators are ecologically valid and repeatable. Chatzinikolaou et al. (2014) and Moreira et al. (2014) examined agility performance during periods of EIMD in elite basketball players using a ‘T-test’, which whilst versatile and repeatable (25), is not assigned to a particular area of a basketball court and is limited to forward, lateral and backward movements. Alternatively, Pyne and colleagues (31) developed a more basketball-specific agility test, which assess the body’s ability to turn and is conducted in an area underneath the basket (a 5 x 7.6m area known as the ‘paint’). This protocol is highly applicable for basketball players given that the capability to turn the body by pivoting the foot is essential (38) and a large period of the basketball match is spent in the 'paint' shooting and contesting the ball (31). Another protocol specific to basketball is the 'suicide' (also known as the 'line drill'), which has been used to identify physiological attributes of basketball players (6). However, no studies have examined the reliability of this protocol nor examined the sensitivity of changes during periods of EIMD.

The aim of this study was two-fold; firstly, to determine whether a basketball-specific training session causes EIMD in elite female basketball players on performance tests. Secondly, to examine the reliability of these performance measures (i.e., basketball-specific agility test and 'suicide' test) that have been specifically developed for basketball players.

Methods

Experimental Approach to the Problem

This study was conducted during the first two weeks of a professional basketball pre-season period, with the physiological tests being conducted on three separate days. During the first week, the participants undertook their first testing session for baseline measures (T_{Base}) involving assessments of indirect muscle damage markers, countermovement jump (CMJ), body mass and basketball-specific performance tests. Immediately following the testing session, a typical basketball-specific training session was conducted. The testing session was repeated 24 hours (T_{24}) following the training session to measure its impact of EIMD on basketball-specific performance measures. One week later, the testing session was repeated (T_{7d}) to determine the reliability of the basketball-specific performance measures. Indirect muscle damage markers were also collected during this testing session to determine whether the athletes were being tested under the same physiological condition for reliability purposes.

Participants

Ten elite female basketball players (age 17-32 years; height 1.79 ± 0.7m; body mass 76.7 ± 8.3kg) who competed in the Women's National Basketball League (WNBL) during the 2016-2017 season volunteered for this study. The WNBL is a professional, Australian competition that consists of a 16-week regular season and 3-week post-season. All players had been regularly participating in competitive basketball matches during the off-season. To minimize the impact of biological variations, each testing session was conducted at the same time of day, having participants wear the same shoes for every training and testing session and refraining from the following activities: high-intensity exercise for at least 72 hours prior to T_{Base} and T_{7d}, caffeine and food intake for at least 2 hours prior to each testing session, taking supplements and medication (e.g., anti-inflammatory aids) and recovery sessions in-between the testing sessions. The participants were informed of the risks involved in the study and then provided written informed consent prior to taking part in the study. The current study was approved by the Institutional Human Research Ethics Committee (HREC) and that all participants were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. This approval covered elite youth athletes providing consent when operating in an adult setting and approved by the local HREC in accordance with the National Health and Medical Research Council national statement. According to an a priori sample size calculation based on previous studies examining indirect muscle damage markers (Doma et al., 2014; Doma et al., 2015), a sample size of 10 participants was sufficient to detect a significant change in variables (>80% of power at an alpha level of 0.05).

Basketball-specific training session

The team head coach designed and conducted a high intensity training session (85 minutes) typically implemented for elite, female, basketball players. As part of the training session, a progressive warm-up was undertaken for 15 minutes consisting of dynamic stretches (i.e., jogging around the court, leg swings in frontal and sagittal planes, body weight walking lunges, high knees, butt kicks and progressive full-court sprints) followed by shooting from the free throw line and three point line (5-10 shots). For the next 30 minutes, participants undertook structured maximal effort sprint-based activities including dribbling, passing and shooting. For example, participants sprinted full court in pairs whilst passing the ball to each other and ending in a shot at the other end of the court. After 5 minutes of recovery, the participants then undertook an intense, full-court, scrimmage session replicating match play that consisted of three, 6-8 minute periods separated by ~5 minutes of rest. To determine the physiological stress induced by the basketball-specific training session, a blood samples were collected prior to and immediately post via finger prick to analyze lactate (Lactate Pro 2, Arkray, Japan, Tokyo).

Indirect muscle damage markers

The countermovement jump (CMJ) was conducted to gain insight of the player's neuromuscular properties during periods of EIMD. Three maximal jump attempts were recorded with 15-30 seconds of rest between each attempt (Yard Stick, Swift Performance, Queensland, Australia), and the greatest jump height subsequently reported. To ensure stability across conditions, the participants were instructed to use their arms to gain momentum, maintain proper posture and body alignment throughout the movement with a self-selected depth, avoid excessive swaying and ensuring that their heels were in contact with the floor during the eccentric movement prior to take-off (2). Based on these jump height measures, lower extremity power was calculated using the following equation (12):

$$Power\ (W) = \sqrt{4.9} \times body\ mass\ (kg) \times \sqrt{jump(m)} \times 9.81$$

From the CMJ test, jump height and lower body power output measures were reported. The participant's level of delayed onset of muscle soreness (DOMS) was determined using a visual analogue scale with 1 defined as "no soreness" and 10 as "very, very sore" (11). The general DOMS (G-DOMS) score was ascertained by asking participants how sore their muscles were overall whilst DOMS of their lower extremity (L-DOMS) was assessed through questioning after they completed a body weight squat until their knees were flexed to approximately 90°. Creatine kinase (CK) levels were measured from a 30-μL fingertip, capillary blood sample using a colorimetric assay procedure (Reflotron, Boehringer Mannheim, Germany). The CK measures were reported from one serum blood sample which was immediately pipetted to a test strip. The previously reported intra-assay coefficient of variation for this assay procedure using the same equipment was 7.2% (10).

Basketball-specific performance tests

Performance assessments previously developed for basketball players were examined in the current study and included a change-of-direction (COD) test and a line drill or suicide test (ST) (31). For the COD test, the participants ran in a zigzag fashion around the cones within a 5 x 7.6m area of the basketball court at maximal effort (Figure 1). Timing gates (Swift performance, Queensland, Australia) were positioned at the starting/finishing line to record test duration. The participants completed the COD test three times at a sub-maximal effort with gradual increases in intensity for each bout for familiarization purposes. Following the familiarization bouts, time of test completion was recorded for three maximal attempts with two minutes of rest between each attempt and the best time reported. The COD test was developed as a basketball specific test that was performed in the restricted area of the basketball court underneath the basket (31). Basketball players were familiar with this type of movement and location due to the game rules that imposed a timing restriction within this area and the game activities typically undertaken in this area (e.g. receive, shoot and contest the ball on missed shots). For ST (31), participants sprinted back and forth between the baseline, and the closest free-throw line, half court, furthest free-throw line and full court line, respectively. Similar to the agility test, timing gates were positioned at the start/finish line to record test duration and the participants performed the test once at sub-maximal effort for familiarization. As participants were very familiar with this test, due to their prior training experience, participants completed only one trial of ST with maximal effort.

Figure 1 around here

Statistical analyses

The measure of central tendency and dispersion was reported as mean±standard deviation. A one-way repeated measures analysis of variance (ANOVA) with Bonferroni's pairwise comparisons was used to identify differences in variables between testing sessions (i.e., T_{Base} vs. T_{24} ; T_{Base} vs. T_{7d}). Effect sizes (Cohen's *d*) were calculated to determine the magnitude of differences between measures with their associated 95% confidence intervals (CI). The interpretation of ES was as follows: ≥0.8 as large, 0.79-0.5 as moderate and <0.5 as small (Cohen, 1988). The repeatability and degree of measurement error of the physical performance measures were examined using intra-class correlation coefficients (ICC; 2-way analysis of variance) and intra-individual CV with associated 95% CI, respectively.

Following confirmation of homoscedasticity, the systematic bias and 95% limits of agreement (LOA) were also calculated to explore the random error of the physical performance measures. The worthwhile differences for the physical performance measures were also computed based on a nomogram using the estimation of the measurement repeatability error in accordance with the CV (26). Worthwhile differences for the current sample size (n = 10) was determined using the linear regression equation: $y = 1.5182x + 0.2382$ (9). All analyses were conducted using the Statistical Package for Social Sciences (SPSS, version 24).

Results

Training-induced stress

The lactate values were significantly increased ($t_{(9)} = -3.903$, p = 0.004; ES = 3.24 [2.11-4.36]) from prior to (1.7±0.7 mmol·L^{-1}) to immediately post (7.2±4.3 mmol·L^{-1}) the training session. Significant differences between testing sessions were identified for CK ($F_{(2, 18)}$ =17.07, p < 0.01), G-DOMS ($F_{(2, 18)}$ = 12.85, p < 0.01), L-DOMS ($F_{(2, 18)}$ = 14.93, p < 0.01), power output ($F_{(2, 18)}$ = 4.69, p = 0.023) and ST ($F_{(2, 18)}$ = 8.31, p < 0.01). Post hoc analyses showed that power output was significantly lower (P = 0.038) while G-DOMS (P < 0.01), L-DOMS (P = 0.011), CK (P < 0.01) and ST performance (P = 0.017) were significantly greater (P<0.05) at T_{24} compared to T_{Base} with all comparisons exhibiting moderate to large ES (Table 1). Jump height was similar across all testing sessions ($F_{(2, 18)}$ = 2.90, p = 0.08) with a moderate ES noted between T_{24} and T_{Base} values (Table 1). There was no significant difference ($F_{(2, 18)}$ = 0.067, p = 0.935) in COD performance between T_{Base} and T_{24} with a small ES (Table 1).

Table 1 around here

Reliability

When measures were compared between T_{Base} and T_{7d}, no significant differences were found for the physical performance measures (power output (P = 0.264), jump height (P = 0.412), COD (P = 1.000) and ST (P = 0.089)) and indirect muscle damage markers (CK (P = 1.000), G-DOMS (P = 1.000), L-DOMS (P = 0.159) with small to moderate ES (Table 2). The repeatability of the physical performance measures based on ICC, mean difference (%), systematic bias, LOA, CV and WD ranged from 0.81-0.95, 0.4%-3.5% 0.03-0.6, 0.4-3.8, 1.5-4.1% and 2.7-6.6%, respectively (Table 2). The Bland Altman plots for jump height, lower body power, COD test and ST test are shown in Figure 2.

Table 2 around here

Figure 2 around here

Discussion

The current study examined the impact of EIMD on basketball-specific performance measures and the reliability of these measures. The training session, which consisted of multiple sprints and jumping exercises, caused EIMD 24 hours post with impairment in jumping ability (i.e., power) and repeated-sprint performance (i.e., ST) although COD performance was not affected. When comparing measures between T_{Base} and T_{7d}, no differences were found for CMJ, power, COD and ST with good to excellent reliability.

The acute responses of basketball-specific training showed that CK, G-DOMS and L-DOMS were significantly increased with a concomitant reduction in jump height and power output at T_{24}, suggesting that muscle fiber damage occurred as a result of the training session. These findings were expected, given that basketball-simulated training involves heavy eccentric loading via deceleration during sprints and jumping actions which causes EIMD (19). The magnitude of changes in CK (i.e., ~2-fold increase) and DOMS (~3-fold increase) and CMJ (i.e., ~6% reduction) in the current study are in line with previous findings 24 hours following a basketball match in elite female (23) basketball players. Similar findings have also been reported 24 hours following a basketball match in elite male (3, 16, 35) basketball players. However, comparisons in these measures should be considered with caution given that gender differences in CK and muscle function have been shown previously (17, 21). Based on the similarity in training background of participants and the degree of indirect muscle damage markers reported from our findings and that by Moreira et al. (2014), it is reasonable to assume that the physiological stress induced by the basketball-specific training session in the current study replicated a basketball match.

Interestingly, Kostopoulos and colleagues (2004) reported a four-fold greater CK level and DOMS 24 hours following a 10-min basketball-simulated training session. However, the participants in their study were recreational athletes that were not regularly exposed to basketball-specific activities. This protection against muscle fiber damage following multiple bouts of exercise with eccentric-loading is known as the repeated bout effect (27) and highlights the importance of accounting for training background and previous training experience when monitoring athletes following high intensity training sessions (11). It is also important to note that the training intensity and volume were not controlled or documented in the current study with the scrimmage during the latter half of the training session potentially resulting in inter-individual variation in training volume. However, the training session was structured to ensure that all participants undertook the same type and number of exercises during the first 30 minutes prior to the scrimmage irrespective of playing position. This approach of incorporating conditioning exercises followed by a scrimmage allows for better monitoring of training volume and is distinct to previous studies that have examined the impact of EIMD following basketball matches only (3, 23).

Whilst indirect muscle damage markers were significantly altered 24 hours following the basketball-specific training session, no changes were found in COD performance. These results are similar to that reported by Moreira et al (2014), where agility/COD performance was unaltered 24 hours following a basketball match in elite female basketball players despite changes in indirect muscle damage markers (i.e., CK, DOMS and CMJ). Interestingly, Chatzinikolaou and colleagues (2014) reported attenuation in agility/COD performance with a concomitant increase in indirect muscle damage markers 24 hours post a basketball match. The discrepancies in these findings may be attributed to the differences in the match playing time of each participant. For example, the participants in the study by Moreira et al (2014) were allowed substitutions during the 40-minute basketball match with an average playing time of 18 minutes. Whilst participants in the current study were not given substitution allowance during their scrimmage, the duration and the number of sets played were substantially less compared to a typical game. Conversely, Chatzinikolaou and colleagues (2014) had each participant play through the entire 40-minute basketball match. Accordingly, the greater level of playing time, and therefore eccentric-loading exposure, may have induced agility/COD performance changes amongst participants in the study by Chatzinikolaou et al. (2014).

In contrast to COD performance, the current study showed that the ST performance was impaired. Given that this is the first study to report on changes in ST performance in response to EIMD, comparing these findings to previous studies was difficult at present. Chatzinikolaou et al. (2014) and Pliauga et al. (2015) reported significant increases in 10-meter sprint times 24 hours following a basketball match in elite male basketball players, suggesting that sprint-ability is impaired as a result of EIMD in such athletes, although repeated-sprint ability cannot be inferred from their findings. Other studies have shown impaired repeated-sprint ability in competitive male soccer players (18, 22), although these results are not directly comparable to the current findings due to differences in the repeated-sprint protocol, athlete-type and gender. Nonetheless, the attenuation in ST performance in the current study provides insight on the impact that EIMD has on repeated sprint performance in basketball players. However, given that every effort was made to equate training volume during the first half of the training session, more research is necessary to confirm whether EIMD is caused by exercise intensity, training volume or by both training variables. In addition, given that performance measures were collected in a highly controlled environment, as opposed to match-situations with unpredictable constraints, further research is needed to confirm whether basketball-specific training sessions cause attenuation in performance during game-play and whether EIMD remains elevated beyond 24 hours following a basketball-specific training session.

The high level of reliability and minimal measurement error for the CMJ and lower body power output measures reported in the current study are in line with previous studies amongst elite basketball players (7, 20). For the COD test, results showed an ICC of 0.81 and a CV of 1.9%, indicating good reliability with minimal measurement error. Furthermore, the systematic bias of the COD test was minor (0.03s) with the LOA being 0.42s and 95% of all between-trial differences within 0.21s of the bias. Recent studies have also shown good reliability measures in COD performance based on ICC calculations in elite senior male (34) and junior male (40) basketball players. Given the similar reliability measures in the current study and that reported by others (34, 40), it appears that the COD performance of both elite female and male basketball players are highly stable across testing conditions.

For the ST test, no significant differences were observed between T_{Base} and T_{7d}. Furthermore, the ICC and CV were 0.90 and 1.5%, respectively, demonstrating excellent reliability. In addition, the systematic bias of this test was minimal (-0.6s) with the LOA being 1.27s and 95% of all between-trial differences within 0.6s of the bias. Studies have previously reported good to excellent reliability using ICC calculations for physical assessments involving multiple repeated sprints in basketball players (28, 40). However, the repeated sprint protocols have typically consisted of identical sprint distances, passive recoveries in-between each sprint and sprint durations of only 4-6s (28, 40). Contrarily, the ST is a continuous protocol for ~30s without recovery and the distance of each sprint increases following each directional change. Subsequently, the ST places more demand on the anaerobic glycolytic system as opposed to the anaerobic system utilized during the shorter sprint performance protocols (15). Whilst short repeated sprints are important performance indicators in basketball (Kostopoulos et al., 2004), situations of having to repeatedly sprint back and forth across the full length of the court without recovery (i.e., ST performance) is common during a basketball game (Scanlan et al., 2014). Thus, the current findings provide insight on the usability of ST to determine performances within basketball-specific constraints and physiological demands.

Practical applications

EIMD was associated with attenuation in vertical jump ability and repeated sprint performance although COD performance was unaffected. Accordingly, trainings sessions consisting of basketball-specific conditioning exercises and scrimmage should be considered with caution if incorporated 24 hours prior to an important basketball match or training session involving repeated high intensity exercises. For the reliability measures, CMJ, power output, COD test and ST were repeatable indicating the usability of these protocols for monitoring fatigue and/or improvement as a result of training adaptation in elite female basketball players.

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Figure captions

Figure 1. The schematic of dimensions for the change-of-direction test

Figure 2. Bland and Altman plots of the differences between baseline and the testing session one week later for jump height (JH; a), lower body power output (Power; b), chance of direction test (COD; c) and suicide test (ST; d)

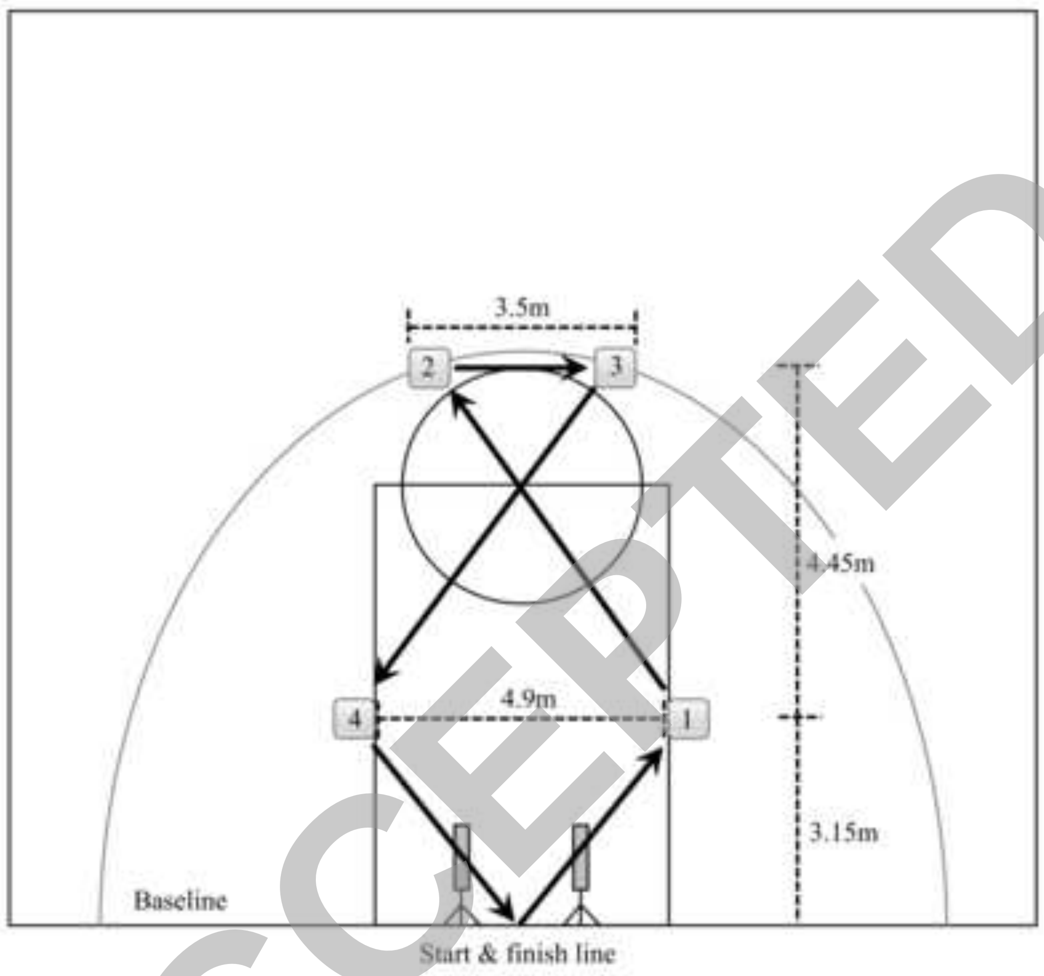
Table 1. Measures of jump height, lower body power (Power), general (G-DOMS) and lower body (L-DOMS) muscle soreness, creation kinase (CK), change-of-direction (COD) and suicide test (ST) prior to the first (T_{Base}), second (T_{24}) and third (T_{7d}) training sessions.

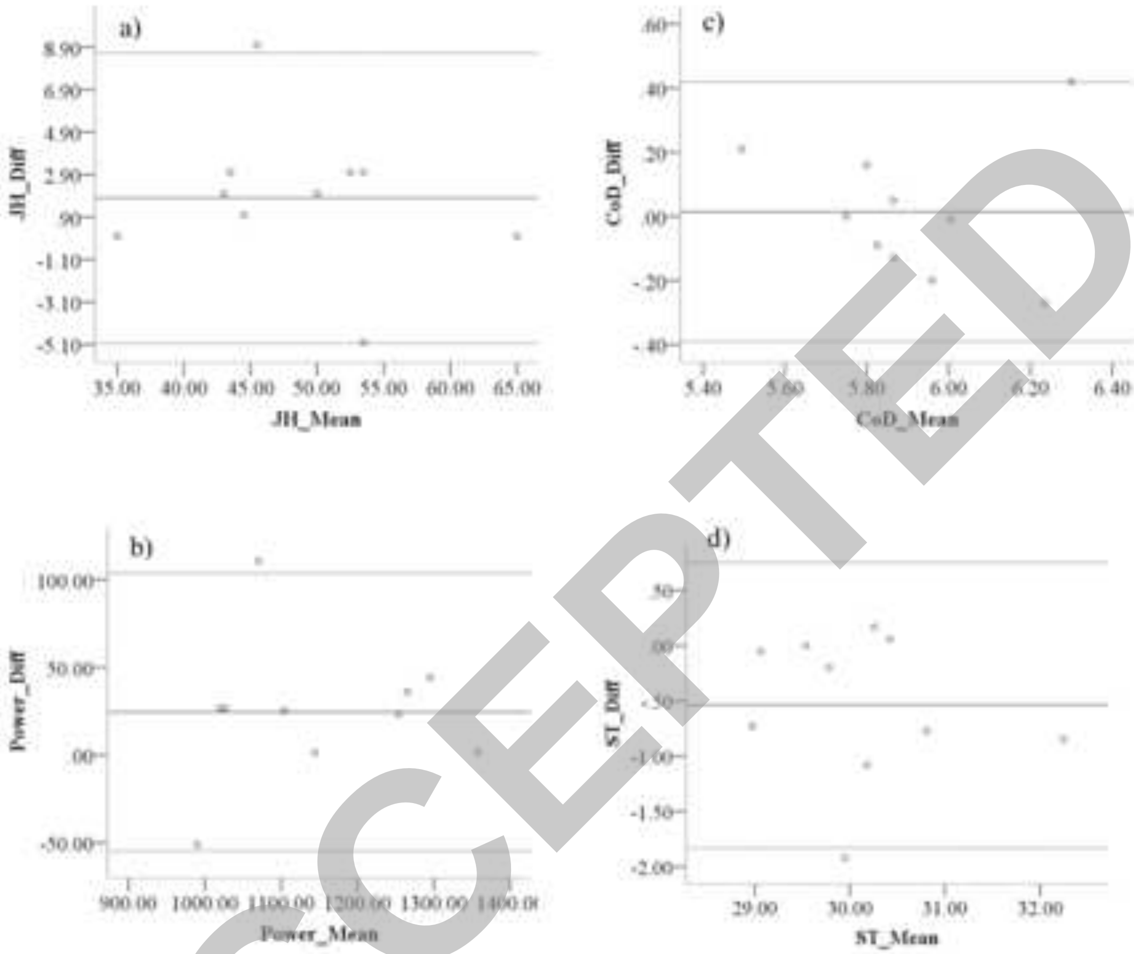
				ES (95%CI)	
	T_{Base}	T_{24}	T_{7d}	T_{Base} vs. T_{24}	T_{Base} vs. T_{7d}
Jump height (m)	0.50 ± 0.08	0.47 ± 0.07	0.48 ± 0.09	0.58 [0.27-0.89]	0.39 [0.02-0.77]
Power (W)	1164 ± 134.3	1122.2 ± 113.5*	1140.4 ± 130.9	0.43 [0.25-0.61]	0.26 [0.02-0.50]
G-DOMS	2.7 ± 1.1	5.6 ± 1.5*	3.1 ± 1.2	1.65 [0.64-2.67]	0.11 [-1.42-1.20]
L-DOMS	2.1 ± 1.0	4.2 ± 1.6*	2.9 ± 1.1	1.31 [0.34-2.28]	0.68 [-0.50-1.85]
CK ($U \cdot L^{-1}$)	145.9 ± 103.7	318.5 ± 102.3*	147.2 ± 67.6	1.04 [0.50-1.55]	0.07 [-0.68-0.82]
COD (s)	5.92 ± 0.25	5.9 ± 0.2	5.9 ± 0.3	0.02 [-0.44-0.39]	0.14 [-0.77-0.50]
ST (s)	29.9 ± 0.9	30.5 ± 1.2*	30.4 ± 1.1	0.84 [0.28-1.39]	0.78 [-0.03-1.58]

*$P<0.05$ vs T_{Base}; ES – effect size; CI – confidence interval.

Table 2. Measures of mean differences (Diff), intra-class correlation coefficient (ICC), average bias (Bias), 95% limits of agreement (LOA), intra-individual coefficient of variation (CV) and worthwhile difference (WD) for countermovement jump (CMJ), lower body power (Power), change-of-direction (COD) test and suicide test (ST)

	CMJ (cm)	Power (W)	COD (s)	ST (s)
Diff (%)	3.5	1.9	0.4	2.0
ICC	0.95 (0.79-0.99)	0.97 (0.88-0.99)	0.81 (0.14-0.96)	0.90 (0.54-0.98)
Bias	0.43	5.72	0.03	-0.6
LOA	3.8	44.54	0.42	1.27
CV (%)	4.1 (0.8-7.4)	2.2 (0.5-2.9)	1.9 (0.7-3.1)	1.5% (0.3-2.6)
WD (%)	6.5	3.6	3.2	2.5


3.5m
2
3
4.45m
4.9m
4
1
3.15m
Baseline
Start & finish line


a)
JH_Diff
JH_Mean
b)
Power_Diff
Power_Mean
c)
CoD_Diff
CoD_Mean
d)
ST_Diff
ST_Mean